

Cooperative Sensing in Cognitive Radio Networks-Avoid Non-Perfect Reporting Channel

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Abstract: Problem statement: Cognitive radio is a candidate technology for more efficient spectrum utilization systems based on opportunistic spectrum sharing. However, a common assumption regarding cognitive radios is that they are unlicensed spectrum users that should defer to (avoid interfering with) existing primary sources. Therefore effective sensing of primary users was a major focus of current research. Cooperative spectrum sensing had been proposed to overcome the problem associated with the local sensing node problem-due to noise uncertainty, fading and shadowing. However, reporting the sensing result required perfect channel to avoid degradation in sensing performance due to fading. It also required a large bandwidth assuming large number of cognitive user. **Approach:** In this study we presented a hard decision auto-correction reporting scheme that directly corrects the errors in the reported bit and further minimizes the average number of reporting bits by allowing only the user with a detection information to report its result. We used analytical formulation to investigate the reporting scheme, by employing such selection technique; the reporting error due to the fading channel was reduced. **Results:** The sensing performance was investigated and we showed through simulations and probabilistic analysis the sensing performance improvements achieved via the proposed method. Numerical result showed much decrease in reporting bit without affecting the sensing performance.

Key words: Cognitive radio, spectrum sensing, cooperation

INTRODUCTION

Spectrum sensing is a base aspect of cognitive radio to insure no interference for the primary (licensed user). However spectrum sensing can be done locally in the node, where it is susceptible to shadowing and fading which could cause a hidden node problem and will degrade the sensing performance. Cooperative sensing is proposed^[1] to overcome the problems associated with local sensing, different cooperative method is discussed that exploit the multiuser diversity in sensing process^[2,3]. Different protocols can be employed in order to report the local sensing result to other secondary users or a common server in centralized or decentralized architecture respectively, the Amplify and Forward (AF) in which a relay transmits the signal obtained from the transmitter without any processing achieved full diversity^[4]. The AF is used in two cognitive user scenarios^[5], where each user considered as a relay for other user signal in the next time slot. The scheme shows a reduction in detection time and increased agility.

In cooperative sensing architectures, the control channel can be implemented using different methodologies. These include a dedicated band, unlicensed band such as ISM and underlay Ultra Wide Band (UWB) system^[6]. In order to minimize communication overhead, different quantization of the local obtained signal is introduced. It was shown that two or three bits quantization was most appropriate without noticeable loss in performance^[7]. In a hard decision (binary quantization) is proposed for arbitrarily large node population^[8]. However, the total number of sensing bits transmitted to the central is large.

Further to minimize reporting bandwidth a two level quantization method was recently proposed^[9], the method identify the users with a reliable information only to report a binary decision (0,1) to the common server as shown in Fig. 1a. However the method reduces the number of reporting bits at the expose of degradation in sensing performance. The results show that misdetection probability P_m is degraded by the imperfect channel and the false alarm probability P_f is bounded by the reporting error probability.

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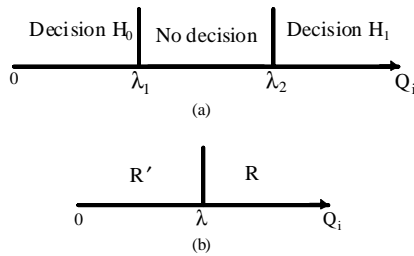


Fig. 1: (a): Censoring detection method with bi-thresholds for the i^{th} user; (b): Auto_correction reporting method with one threshold for the i^{th} user

This means that spectrum sensing cannot be successfully conducted when the desired P_f is smaller than the bound \bar{P}_f . If the channels between cognitive users and the central server are perfect the local decision will send to central server without error. In practice, the reporting channels may experience fading which will deteriorate the performance of the cooperative spectrum sensing. A cluster based method was proposed^[10] where the most favorable user in each cluster is selected to report to central server, the method improved the sensing performance compared to conventional sensing.

In this study, we propose a reporting scheme that auto correct the error in the sensing results reported to the central server. By allowing only the users with detection information to report their local detection result to the central sever, the server will know that whatever signal it receives from a cognitive user it means a detection of a primary user (local decision 1). If it receives an error signal due to imperfect reporting channel it auto corrects it to 1. The method has two advantages: it reduces the number of reporting bits and it corrects the error in reporting signal. Further, the scheme obviates the need of a decision fusion method at the central server. The sensing and detection of primary users was evaluated that insure the method does not degrade the sensing performance and the algorithm acts as it has a perfect reporting channel.

The rest of this study is organized as fellow. First, the materials and methods discuss the proposed auto correction reporting scheme and the system model. The then, the results analyze the performance of cooperative sensing for the scheme and the simulation result is shown. Lastly we conclude the study.

MATERIALS AND METHODS

Autocorrecting reporting model: In our model, every cognitive user conducts a local sensing and if a primary user detected, a hard decision ‘1’ is sent to central

sever, otherwise no report decision is taken. In this case if the server receives a local decision ‘0’ due to imperfect reporting channel, it has a pre-knowledge that only detection result is reported so it auto corrects the reported error.

For simplicity we assume that the local sensing method used is energy detection based where the output of integrator Q is compared with a threshold λ to decide whether a primary user is present or not.

If Q exceed the threshold, a reporting decision R is taken and binary decision ‘1’ is sent to central sever, otherwise ‘no report’ decision R' is taken. This is given by:

$$R = \begin{cases} 0 & Q < \lambda \quad R' \\ 1 & Q > \lambda \quad R \end{cases} \quad (1)$$

The system model of our interest is shown in Fig. 1b.

Following the work of^[11] where the white noise is modeled as zero mean Gaussian random variable and the signal term as zero mean Gaussian variable as well, the decision metric R of the energy detector follows the distribution:

$$R \sim \begin{cases} X_{2m}^2 & H_0, R' \\ X_{2m}^2(2\gamma) & H_1, R \end{cases} \quad (2)$$

where, m is the time bandwidth product and X_{2m}^2 and $X_{2m}^2(2\gamma)$ represent the central and non-central chi-square distribution with $2m$ degree of freedom respectively and non centrality parameter of 2γ for the later. The SNR γ is exponentially distributed with mean value $\bar{\gamma}$ assuming the channel expresses Rayleigh fading.

Assume that the receiver receive K (where $K = 0, 1, \dots, N$) out of N local decision ‘1’ reported form the cognitive users.

If the server receives local decision ‘0’ it is considered as a reporting error due to imperfect channel and is auto corrected to ‘1’.

The final decision H at the server is done based on K . If the server receives any local decision ‘1’ or ‘0’, a final decision $H = 1$ is taken. If no local decision is reported to the server, then a final decision $H = 0$ is taken. H is given by:

$$H = \begin{cases} 1 & K \geq 1 \\ 0 & K = 0 \end{cases} \quad (3)$$

Let \bar{K} denotes the normalized average number of reporting bits

$$\bar{K} = \frac{K_{avg}}{N} \tag{4}$$

where, K_{avg} is the average number of reporting bits.

Let R_K represents the event that there are K cognitive users reporting and \bar{R}_{N-K} represent the event that there are $N-K$ cognitive users not reporting, then:

$$P\{R_K\} = 1 - P\{Q < \lambda\} \tag{5}$$

$$P\{R_{N-K}\} = P\{Q < \lambda\} \tag{6}$$

Further, let $P_0 = P\{H_0\}$, $P_1 = P\{H_1\}$. Then, the average number of reporting bits is given by:

$$K_{avg} = P_0 \sum_{K=0}^N K \binom{N}{K} P\{\bar{R}_{N-K} | H_0\} + P_1 \sum_{K=0}^N K \binom{N}{K} P\{R_K | H_1\} \tag{7}$$

$$\bar{K} = 1 - P_0 R'_0 - P_1 R'_1 \tag{8}$$

where, R'_0, R'_1 represent the probability of “No report” under hypothesis H_0, H_1 respectively:

$$R'_0 = P\{Q < \lambda | H_0\}, R'_1 = P\{Q < \lambda | H_1\} \tag{9}$$

From (8) it can be shown that the normalized average number of reporting bits \bar{K} is always smaller than 1.

Spectrum sensing performance analysis: If the channel between cognitive users and the central server are perfect and a full reporting is employed, the detection probability P_d , the false alarm probability P_f and the misdetection probability P_m are given by^[10]:

$$P_d = 1 - \prod_{k=1}^N (1 - P_{d,k}) \tag{10}$$

$$P_f = 1 - \prod_{k=1}^N (1 - P_{f,k}) \tag{11}$$

and

$$P_m = \prod_{k=1}^N P_{m,k} \tag{12}$$

where, $P_{d,k}, P_{f,k}, P_{m,k}$ are the detection probability, the false alarm probability and the misdetection probability for the k th cognitive user, respectively.

Under Rayleigh fading, γ would have an exponential distribution. In this case, the Cumulative Distribution Function (CDF) of collected energy Q under hypothesis H_0, H_1 is:

$$F(\lambda) = \int_0^\lambda f(Q|H_0) dQ = 1 - \frac{\Gamma\left(m, \frac{\lambda}{2}\right)}{\Gamma(m)} \tag{13}$$

and

$$G(\lambda) = \int_0^\lambda f(Q|H_1) dQ = 1 - e^{-\frac{\lambda}{2}} \sum_{k=0}^m \frac{1}{k!} \left(\frac{\lambda}{2}\right)^k + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{m-1} \times \left(e^{-\frac{\lambda}{2(1+\bar{\gamma})}} - e^{-\frac{\lambda}{2}} \sum_{k=0}^{m-2} \frac{1}{k!} \left(\frac{\lambda \bar{\gamma}}{2(1+\bar{\gamma})}\right)^k \right) \tag{14}$$

Then R'_0, R'_1 can be written as:

$$R'_0 = F(\lambda), \quad R'_1 = G(\lambda)$$

where, $\Gamma(\dots), \Gamma(\cdot)$ are incomplete and complete gamma functions, respectively^[12].

In case $K = 0$, no report is sent to the server, here no primary user considered active in the frequency band. Let β_0, β_1 denote the probability of “no report” under hypothesis H_0, H_1 , respectively:

$$\beta_0 = P\{K = 0 | H_0\} = (R'_0)^N \tag{15}$$

$$\beta_1 = P\{K = 0 | H_1\} = (R'_1)^N \tag{16}$$

Here the detection probability P_D , the false alarm probability P_F and the misdetection probability P_M are given as follows:

$$P_D = P\{H = 1, K \geq 1 | H_1\} = 1 - \beta_1 \tag{17}$$

$$P_F = P\{H = 1, K \geq 1 | H_0\} = 1 - \beta_0 \tag{18}$$

and

$$P_M = 1 - P_D \tag{19}$$

In Eq. 19, it can be observed that the performance of cooperative sensing is not degraded due to imperfect reporting channel, the method auto-corrects the reporting error and thus create virtual perfect reporting in an imperfect channel.

RESULTS

Simulation results: Simulation results demonstrate the performance of cooperative spectrum sensing under auto correction reporting scheme and provide a comparison with the existing method, the results of the conventional method and the censoring method with quantization (with probability of fail sensing equal to 0.001)^[9] are given for a comparison. We assume that the number of cognitive user is 10 users in the system and the average SNR between the primary user and any cognitive user is 10 dB. We use $P_0 = 0.5$.

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Figure 2 shows that the normalized average reporting bits have been decreased compared with the conventional method and the censoring method

Figure 3 shows the tradeoff between the spectrum sensing performance and the average number of reporting bits, i.e., P_M Vs \bar{K} , for given false alarm probability, $P_F = 0.0001, 0.001, 0.005$, respectively. It can be observed that, for a fixed false alarm probability, the missing probability P_M changes a little when \bar{K} varies from 0.5 to 1, which means that we can achieve a large reduction of number of sensing bits at a very little expense of performance loss.

Fig. 4 illustrates the complementary receiver operating characteristic performance (P_M Vs P_F) of cooperative spectrum sensing, for the different reporting method. The curves for the auto_correction reporting scheme and conventional method (assuming perfect reporting channel for the latter) are the same which means there is none or unobserved performance loss of spectrum sensing reporting performance due to fading in reporting channel, which justify the analysis.

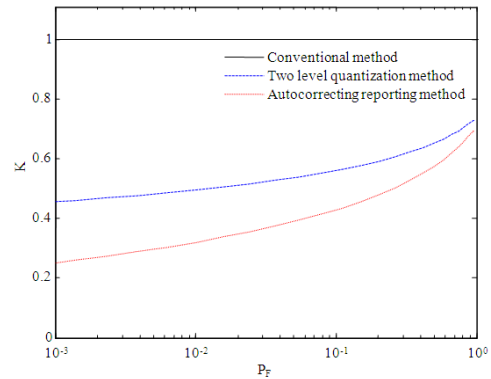


Fig. 2: The normalized average number of sensing bits \bar{K} Vs P_F , $N = 10$ and $SNR = 10$ dB

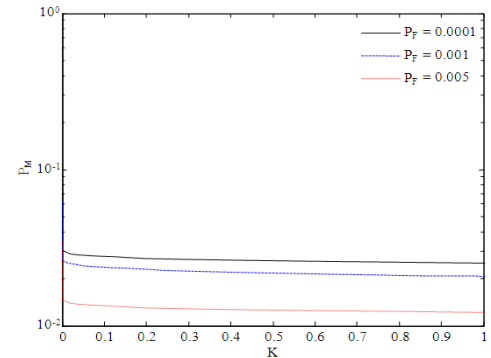


Fig. 3: P_M Vs \bar{K} , $N = 10$ and $SNR = 10$ dB

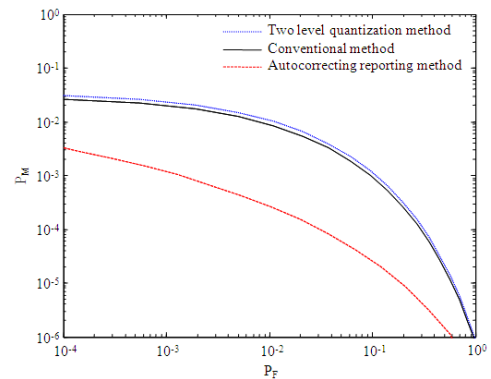


Fig. 4: Complementary Receiver Operating Characteristic (ROC) (P_M Vs P_F) of cooperative spectrum sensing, $N = 10$ and $SNR = 10$ dB

DISCUSSION

Performance in a spectrum sharing network involves evaluation of a number of system characteristics. Of primary importance is the tradeoff between minimizing interference with primary users and maximizing spectral efficiency, a relationship

directly related to the Receiver Operating Characteristic (ROC) curves of the cooperative sensing system. However, any spectrum sharing network designed for spectral efficiency would have stringent constraints on control-channel bandwidth. It has been shown that cooperative spectrum sensing needs a control channel for each cognitive radio to report its sensing result and the control channel is usually bandwidth limited. If every cognitive radio transmits the real value of its sensing observation, infinite bits are required and this will result in a large communication bandwidth. Quantization of local observations has attracted much research interest even though it introduces additional noise and a Signal-to-Noise Ratio (SNR) loss at the receiver. In our systems, using binary quantization and only the users with detection information are allowed to send to the common receiver, the system achieve a large reduction of number of sensing bits at no expense of performance loss.

CONCLUSION

As far as the cognitive network grows, the coordination algorithm should have reduced protocol overhead. To decrease the average number of reported bit a reporting method for the result of the cooperative spectrum sensing in cognitive radio network with error auto correction scheme is discussed in this study. The performance of the proposed method in spectrum sensing is analyzed; the normalized average number of reported bits has been derived. Simulation results shows the decrease in reporting bits without performance loss compared with existing methods.

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